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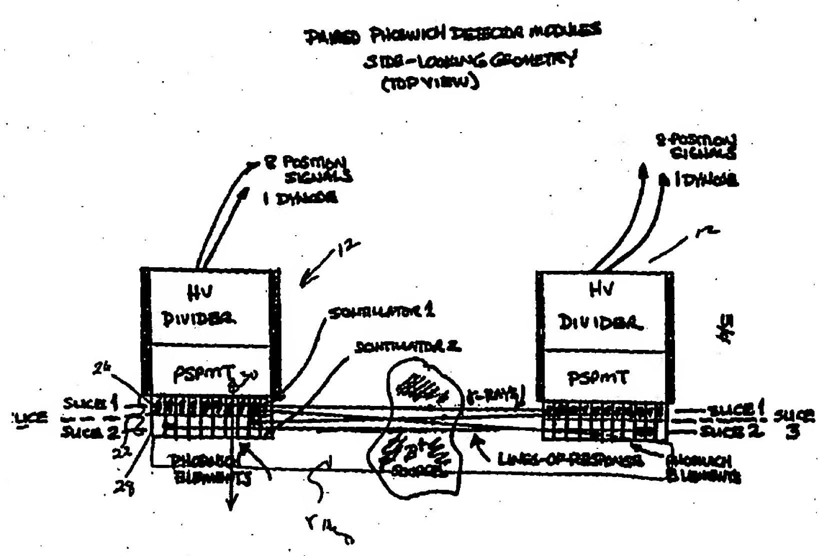

(57) Abstract

An improved PET scanner utilizes detectors having crystals oriented in a side-looking geometry with their long axes parallel to the ring axis. Phoswiches having multiple scintillators with different signatures and identification circuitry for identifying which scintillator is activated are utilized to reduce slice thickness.

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A MULTI-SLICE PET SCANNER FROM SIDE-LOOKING PHOSWICH SCINTILLATORS

BACKGROUND OF THE INVENTION

1. Field of the Invention.

The present invention relates generally to the field of imaging biological tissue and, more particularly, relates to improvements in positron emission tomography (PET) imaging devices and techniques.

2. Description of the Relevant Art.

Positron emission tomography (PET) is a technique of measuring the concentration of a positron emitting isotope through sectional planes or within a defined volume of the body of a human being or animal.

Some isotopes undergo a transition of atomic number where a proton decays into a neutron, positive electron (positron), and a neutrino. The positron interacts with an electron and the two particles annihilate each other to emit a pair of gamma rays travelling in opposite directions and each having an energy equal to 511 keV.

Fig. 1 depicts a ring-type PET (positron emission tomography) scanner 10 having a plurality of detector modules 12 facing inward towards the center of a ring 14. A ring-axis 16 passes through the center of the ring 14 and the ring 14 is oriented perpendicularly to this ring-axis 16.

Fig. 2 depicts a detector module 12 composed of an array 20 of individual scintillation elements 22, or "pixels," optically coupled to a miniature position-sensitive photomultiplier tube (PSPMT) 24. Each scintillation element 22 in the array 20 is a "phoswich" of two or more different scintillators 26 and 28, aligned along a common long-scintillator-axis 30 and optically coupled together. Each phoswich element 22 is surface-treated to enhance

transmission of light toward one end (the end of the element optically coupled to the PSPMT). These individual phoswich elements 22 are then bundled tightly together, oriented with their common long-scintillator-axes 30 parallel, to form a regular array 20 that is coupled *en masse* to the face of the PSPMT 24.

Note that each phoswich element 22 is formed as a rectangular cylinder having a rectangular base 22b and a length 221 being substantially greater that the width of the base 22b. The elements 22 in the array 20 are clustered so that a planar face of the array (of dimensions X x Y) is formed by the rectangular bases 22b and the lengths of the cylindrical elements 22 are parallel to each other and to a detector-axis 32 oriented perpendicularly to the detector face.

There are several factors which limit the angular and positional resolution of a ring-type scanner 10. One factor is the depth-of-interaction (DOI) effect which is schematically illustrated in Fig. 3, where the annihilation takes place away from the center of the ring. A gamma ray is detected in a single crystal. If the gamma rays are emitted parallel to the diameter of the ring (tangential projection) then each ray traverses only a single crystal and the spatial resolution is about equal to the width of a detector element, e.g., about 2 mm. However, if the gamma rays are emitted perpendicularly to the diameter of the ring (radial projection) then each gamma ray may traverse several crystals. There is some probability that the ray will interact with any of the traversed crystals so that the resolution is spread over the radial projection of the traversed crystals on the diameter of the ring, as illustrated in the figure.

SUMMARY OF THE INVENTION

According to one aspect of the invention, a new multi-slice PET scanner is based on (1) a detector module consisting of a miniature position-sensitive photomultiplier tube (PSPMT) coupled to a pixelated array of "phoswich" scintillators (2) onto which annihilation radiation falls, not

from the front (as is usually the case), but from the side, (3).

According to another aspect of the invention, a number of these modules are arranged around a ring alternating from one side of the ring to the other such that the pixel bundles touch each other without significant intervening dead space, and where each detector module is placed in time coincidence with a group of detectors on the opposite side of the ring.

According to another aspect of the invention, lines-of-response (LORs) are generated in this geometry by detection of coincidence events in modules on opposite sides of the ring. A scintillation event in one of the individual phoswich elements allows that element to be identified by the PSPMT.

According to another aspect of the invention, if the two scintillators differ in their light decay times, the phoswich light flash can also be examined to determine which scintillator in the element was responsible for the interaction. In the side-looking geometry, identification of the scintillator is equivalent to identifying the slice plane in which the event occurred.

According to another aspect of the invention, the number of axial "slices" available thus depends on the number of uniquely identifiable scintillators in the phoswich element, e.g., two scintillators will yield a three-slice scanner, two real slices and one cross slice.

According to another aspect of the invention, the "side-looking" nature of the phoswich array also causes in-plane spatial resolution to vary slowly across the field-of-view, essentially independent of ring diameter, thereby permitting small ring diameters.

Other features and advantages of the invention will be apparent in view of the following detailed description and appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross-sectional view of one plane of crystals and detectors in a conventional PET scanner;

Fig. 2 is a cross sectional view of a position sensitive gamma ray detector;

Fig. 3 is a schematic cross sectional view illustrating the depth-of-interaction (DOI) effect;

Fig. 4 is a cross-sectional view of two detectors oriented in a side-looking geometry; and

Figs. 5A and B are side and top views, respectively, of a staggered side-looking detector array.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Properties of Side-Looking Phoswich Detectors

As described above, scintillation crystals 22 in detector 12 modules used for PET are most often oriented with their long axis 30 perpendicular to the ring axis 16, i.e. forward-looking.

Figure 4 depicts novel a side-looking geometry, where the long axis 30 of each crystal is parallel to the ring axis 16, thereby eliminating the above-described "depth-of-interaction" effect associated with forward-looking crystal arrays.

As set forth above, in a ring-type PET scanner the accuracy of line-of-response (LOR) positioning deteriorates as a point source of radioactivity is moved off the axis of the scanner. The primary reason for this is that, for off-axis sources, annihilation photons can enter crystals through their sides and interact anywhere along the length of the crystal. Since LOR positioning accuracy depends on where the photon interacts in the crystal, and this position (or depth) is unknown, LOR positioning suffers.

The side-looking configuration depicted in Figure 4 does not suffer from this effect, since the endpoints of each LOR are directly determined for each event, i.e. by the X,Y coordinate of the element in which the event occurred. It follows, therefor , that if a source of radioactivity is moved

radially off the axis of a ring of side-looking detectors, LOR positioning accuracy will not change, and spatial resolution in the transverse plane will be essentially independent of radial position. Similarly, transverse spatial resolution will be largely independent of ring diameter. Thus, by using side-looking detectors, transverse spatial resolution can be maintained constant over the full ring area for small ring diameters.

A practical consequence of this fact is that a complete ring can be made from fewer detectors modules at lower cost. In addition, a small ring diameter would also improve transverse spatial resolution by minimizing the deleterious effects of non-collinear annihilation events.

Further, transverse spatial resolution would be determined largely by the cross-sectional area of each phoswich element and the scintillation efficiency of each component scintillator and could be better than 1.5 mm for some combinations.

Finally, the side-looking configuration as described here presents a substantial thickness of scintillator to incoming annihilation photons equal to the width of the phoswich element array. In the example module, this thickness is 18 mm (2mm/pixel x 9 pixels). At 511 keV, the linear attenuation coefficient of LSO is 0.86/cm and for BGO, 0.95/cm. The fraction of incident 511 keV photons interacting in 18 mm of LSO is 0.79 and 0.82 for BGO.

The primary variables against which these factors must be weighed is the variability in *axial* slice width across the field-of-view, and sensitivity. For a given ring diameter, apparent slice width increases linearly with increasing radial distance from the ring center, but at a fixed radial distance, decreases linearly with increasing ring diameter. Detection sensitivity varies with the square of the total length of the phoswich element and inversely with ring diameter. Thus, high sensitivity can be achieved by using a small ring diameter and the greatest possible total length of phoswich element. However, in order to keep axial slice thickness small across the field-of-view, a phoswich element

of given total length must be made up (ideally) of many short, distinctly identifiable scintillator segments. Although this strategy will not change the percentage variation in axial slice thickness across the field-of-view, the change in absolute thickness will be small, as it must be in small animals. This variation in apparent slice thickness across the field-of-view is the single most significant deficiency in the side-looking array concept and, unless minimized, will complicate quantification of organ tracer content in animals with body cross sections comparable to the ring diameter. It is possible, however, that new, iterative reconstruction methods such as 3D ML-EM that partially model system performance can reduce the magnitude of this effect.

<u>An Example PET Scanner Constructed form Side-Looking Phoswich Detectors</u>

Physical Characteristics

In order to construct a PET scanner, a number of the phoswich detector modules described above are arranged around a ring (a circular ring, square ring, or some other closed arrangement) so that all possible lines-of-response can be acquired, while the radioactive target inside the ring remains stationary. The spatial arrangement and orientation of these modules should be such that little dead space exists between adjacent modules. In order to accomplish this, the modules are arranged as shown in Figures 5A and B.

In reality, each PSPMT has a useful field-of-view that is smaller than the overall cross-section of the tube so a dead region exists around each phoswich array. If these arrays are to be packed together with high density, the PSPMTs must be arranged in alternating, staggered fashion from one side of the ring to the next. As depicted in Figs. 5A and B, detector modules 12 are alternately positioned on the near (N) and far (F) sides of the ring 14. In this configuration, each phoswich array can physically touch the array next to it with only a small angular gap in between. If all of the PSPMTs were on the same side of the ring, each array would be spaced apart by twice the dead space around a single array, an

unacceptably large gap. Fortunately, the length of the PSPMT-voltage divider combination is small so that placing these modules in this orientation does not cause the overall axial width of the final scanner to be excessive.

When these detector modules are arranged around a ring or square and placed in time coincidence, a high packing fraction, nearly solid annulus of scintillator is presented to incoming annihilation photons.

In general, the number of tomographic slices (N) that can be created with a phoswich detector having M different scintillators is $N = 2 * M - 1$, so for the two scintillator phoswich we are using as $N = 3$ as an example. If we assume a ring diameter of 10 cm, and each phoswich array is 1.98 cm across, 16 detector modules are needed. If each detector module is a 9 x 9 array of phoswich elements, a total of 1,296 phoswich elements is required, and twice this number of scintillators (1,296 of BGO, 1296 of LSO).

The coincidence sensitivity of this system can be estimated for a line source lying along the ring axis and containing 1 microCurie of positron emitter per centimeter of source length. The number of coincidence pairs per second incident onto the full detector ring is given by the relation:

$$R\ (\text{incident}) = (2.33 \times 10^5/\text{sec})\ (0.8)^2/(10) = 1.5 \times 10^4/\text{sec}.$$

As noted earlier, at 511 keV the linear attenuation coefficient of LSO is 0.86/cm and 0.95/cm for BGO. The fraction of incident 511 keV photons interacting in 18 mm of LSO is 0.79 and 0.82 for BGO. If a typical value for the absorbed fraction of 0.80 is assumed, then the (maximum) detected coincidence rate should be:

$$R(\text{detected}) = (1.5 \times 10^4)(.8)^2 = 10^4/\text{sec (approximately)}$$

This calculation ignores the effects of scatter rejection (photofraction), a packing fraction less than 100% and other factors that will reduce this value further. The detected event rate in each "real" detector ring would be about 1/4th this value, i.e. 2500 events/sec while the event rate in the single cross-slice would be equal to about half this value, i.e. 5000 events/sec.

The radial variation of axial slice thickness can also be estimated.

For a 10 cm ring diameter, an object 4 cm across will appear to be sampled with a slice thickness

$$(2/5)\ (0.2\text{ cm}) + 0.2\text{ cm} = 0.28\text{ cm}$$

at its outer edge and with slice thickness 0.2 cm at the center. The percentage variation of slice thickness is thus large (40%), but the absolute difference in slice thickness is small (0.8 mm). As noted earlier, methods should be explored to reduce this fractional variation to a more reasonable level, possibly by incorporating this effect into an ML-EM type reconstruction algorithm.

In summary, in a preferred embodiment the side-looking, phoswich detector PET scanner should have the following characteristics:

1. Ring diameter - 10 cm face-to-face
2. Useful transverse field-of-view - 6 cm
3. Axial field-of-view - 8 mm
4. Axial slice thickness - 2 mm at ring center, 2.8 mm at 2 cm off-center
5. Transverse spatial resolution (best) - 1.5 - 2.0 mm, center-to-edge
6. Number of slices - 2 real, 1 cross slice
7. Number of detector modules - 16
8. Number of scintillator elements - 1,296 LSO, 1, 296 BGO
9. Detector orientation, type - side-looking, phoswich
10. Number of phoswich scintillators per element - 2
11. Scintillator types - LSO, BGO
12. Estimated (maximum) line source sensitivity (total) - 10,000 cps/uCi/cm
    - real slice(s) - 2500 cps/uCi/cm
    - cross slice - 5000 cps/uCi/cm

<u>Detector Module</u>

As described above with reference to Fig. 2, the detector module 12 is composed of an array of individual scintillation elements, or "pixels 22," optically coupled to

a miniature position-sensitive photomultiplier tube (PSPMT) 24. Each scintillation element in the array is a "phoswich" of two or more different scintillators 26 and 28, aligned along a common detector axis 30 and optically coupled together. Each phoswich element is surface treated to enhance transmission of light toward one end (the end of the element optically coupled to the PSPMT). These individual phoswich elements are then bundled tightly together to form a regular array that is coupled *en masse* to the face of the PSPMT. Without limiting the number of variations permitted by this design, a specific embodiment will be described below to illustrate the concept.

The useful field-of-view of current miniature PSPMTs 24 is about 20 mm x 20 mm. This area can be fully covered by a 9 x 9 array of phoswich elements 22, each 2 mm x 2 mm x 8 mm long (2 different scintillators 26 and 28 end-to-end, each 4 mm long), with a unit cell spacing of 2.2 mm. The cell spacing arises because each phoswich element 22 is double-wrapped along its length with teflon tape to enhance light output, including the end of the element farthest from the face of the PSPMT.

Typically, the scintillator 28 in the phoswich element 22 in contact with the PSPMT 24 will be flat and polished on all six sides. The scintillator 26 in the element farthest from the PSPMT will be flat and polished on five sides, with the distant end being rough ground to enhance random redirection of reflections from that end.

If additional, different scintillators are to be added to the element to increase its length, they would simply be made flat and polished on all sides and inserted between the end scintillator and the scintillator in contact with the PSPMT. As will be described below, the number of uniquely different scintillators in the phoswich element will determine the number of tomographic "slices" that can be made with the scanner.

Choice of Number and Kind of Phoswich Scintillators

Scintillation light emanating from a phoswich element 22 and falling on the photocathode of the PSPMT 24 must be sufficient to allow that phoswich element 22, and the identity of the interacting scintillator 26 or 28 in that element, to be accurately identified, i.e. the phoswich element must, in total, be efficient in producing and transmitting light from within the element onto the photocathode.

The scintillators in an element must also meet the following conditions to the greatest possible degree: similar indices of refraction, good transmission of emission light from the other scintillators in the element, similar (high) stopping power for 511 keV photons, a light pulse duration sufficiently different from the other scintillators in the element to be readily distinguished from them, but not so long as to compromise count rate performance.

Related issues that also affect light output from an element include the order of placement of scintillators along an element if the scintillators differ appreciably in light output or other properties (as is the case in reality), the aspect ratio of the element (ratio of cross-sectional area to length), and the surface treatment of the element. Each of these factors affects the amount of light reaching the photocathode.

The maximum number of scintillators (and, thus, the maximum number of tomographic slices) that can be used to form a complete phoswich element is ultimately determined by the availability of scintillators with the properties just noted and by the condition that enough light must reach the photocathode from an element to allow accurate identification of that element and the scintillator in that element. A phoswich detector will necessarily have light refracting and reflecting boundaries at the junctions between adjacent scintillators. Light loss will occur every time light crosses one of these interfaces unless there is an exact match in refractive index between adjacent scintillators and no air gap in between. Real scintillators differ in refractive index by

both small and large amounts so that some light loss from this effect must occur even under the best of circumstances..

If the requirement is added that the scintillators in the phoswich must all possess high stopping power at 511 keV, and also differ significantly in light decay time, the available choices of scintillators becomes substantially smaller, and appreciable differences in properties must be tolerated. As a practical matter, only 3 non-hygroscopic scintillators are available at present that come close to meeting the necessary requirements: GSO, LSO and BGO. The properties of these three scintillators, and the hygroscopic scintillators NaI(Tl) and CsI(Na) are listed below in Table I.

TABLE I

	1/mu (1/cm)	lamba max (nm)	n	photon/Mev	light decay time (nsec)
BGO	1.11	480	2.15	8200 (22%)	*60 (10%), 300 (90%)
LSO	1.22	420	1.82	30000 (80%)*	40
GSO	1.50	440	1.85	10000 (26%)*	60
NaI(Tl)	3.05	415	1.85	38000 (100%)*	230
CsI(Na)	2.43	420	1.84	39000 (103%)*	630

*Percent of NaI(Tl)

1/mu = radiation length, mu = linear attenuation coefficient at 511 keV

lambda max = wavelength of maximum fluorescent light emission

n = index of refraction

photons/Mev = scintillation efficiency

light decay time = 1/e decay time of scintillation light flash

Source:

Derenzo, S.E., Moses, W.M, "Experimental Efforts and Results in Finding New Heavy Scintillators," LBL report - 33295, UC - 407, September, 1992. Results shown here for GSO differ from values reported by Hitachi, the principle manufacturer of GSO. Hitachi reports that GSO light decays bi-exponentially with decay times of 45 nsec (avg.), (90%) and 600 nsec, (10%). 1/mu is also different, 1.38, as well as the wavelength of peak emission, 430 nm.

Additionally, a new GSO detector that varies the scintillation signature in a single crystal by varying the doping levels along the long-axis of the crystal has been announced.

Although a three-scintillator phoswich can be made, at least in principle, from the scintillators in this list, the embodiment described below utilizes a phoswich 22 made from only two crystals, BGO and LSO. This combination offers high, and similar, stopping power at 511 keV, a difference in light pulse duration that should allow easy distinction between scintillators (40 vs. 300 nsec decay times), wavelength of maximum emission that falls within the useful range of the PSPMTs and a difference in scintillation efficiency that should help to overcome light loss due to absorption in the crystal, surface treatment and interface transits (LSO, 30000 photon/Mev compared to BGO, 8200 photons/Mev).

It should be noted that experiments have already shown that events occurring in 1 cm long BGO pixels coupled directly to PSPMTs can be accurately located.

The principle difficulty with this combination is the large difference in refractive index between LSO and BGO: 1.82 vs. 2.15. **Note that the above-described variably doped GSO crystal would not be subject to these difficulties.** This difference will cause significant losses when light transits the interface between these pixels, and may, in fact, reduce the light output from BGO below that just noted above for individual 1 cm BGO pixels. In this latter case, each BGO

pixel was wrapped on five sides with teflon tape so that some fraction of the light falling onto the photocathode must have been reflected from this bottom surface. In the phoswich configuration, light that would have fallen onto the bottom of the 1 cm pixel now passes across a BGO/LSO interface before reaching the bottom surface of the (LSO) element. Light that does reach the bottom and is reflected back must, again, pass across the BGO/LSO boundary and then onto the photocathode.

In what follows below, a two scintillator phoswich comprised of BGO and LSO where the BGO is coupled directly to the PSPMT is analyzed, where each scintillator is 4 mm long and that both have a 2 mm x 2 mm cross-section. All surfaces of the BGO pixel are ground flat and polished while five surfaces of the LSO pixel are ground flat and polished. One of the ends of each LSO pixel is ground flat but not polished to leave that end diffusively reflective. The two scintillators are aligned and coupled together at their polished ends with optical grease having (desirably) an index of refraction midway between LSO and BGO, but in any case without an air boundary. This phoswich is then double-wrapped with diffusely bright white teflon tape to cover all five sides except the polished end of the BGO crystal.

Eighty-one such elements are then packed together into a 9 x 9 array that, in turn, is coupled with optical grease to the face of an R5900U-00-C8 PSPMT manufactured by Hamamatsu. Many pairs of these detector modules, the characteristics of which are described below, form the basic detection element of the side-looking, phoswich PET scanner

<u>Element and Scintillator Identification in the Phoswich Detector Module</u>

<u>Element Location</u>

A light flash occurring anywhere along the length of a phoswich element will give rise to light falling on a localized part of the photocathode of the PSPMT. The Hamamatsu R5900U-00-C8 PSPMT has eight anode wires, four wires for X and four for Y position identification. For every

scintillation event, each of these wires is read-out by a charge-integrating ADC such as the FERA type.

These signals can be analyzed in a number of ways to identify the phoswich element in which the event most likely occurred. For example, the wire signals can be used in a standard "centroid" calculation to compute the X and Y position of the phoswich element. Lookup tables can also be employed that use calibration procedures that link a range of signal values to a particular phoswich element. Vector sum methods can also be used in which regions of "signal space" are connected with phoswich element locations.

All of these methods have certain advantages but all seek the same end, to locate the phoswich element in which the scintillation occurred.

Scintillator Identification

As noted above, the scintillators selected to comprise the phoswich element must differ enough in their light decay times as to be distinguishable from one another. The analysis is continued by considering how the scintillator is identified for the BGO/LSO combination treated above. BGO has a much longer light decay time that LSO. Thus, a simple method for identifying the interacting scintillator might be to split the last dynode signal from the PSPMT (a signal also used for coincidence timing), and integrate each of the split signals for a different integration period. For the BGO/LSO combination, the integration times might be chosen to be 500 nsec and 150 nsec, respectively.

Scintillator identification would be determined by comparing these two values at the end of the 500 nsec period. If the 150 nsec and 500 nsec integration yielded basically the same value, then the "hit" scintillator had to be LSO since its light pulse is essentially over at 150 nsec and further integration will not change the integral significantly. On the other hand, comparison of the 150 and 500 nsec integral for a BGO pulse would differ substantially since only a portion of the BGO light has emerged by 150 nsec. Further integration will continue to increase the BGO integral

relative to the 150 nsec integral and so identify the hit as being in BGO.

Other more elaborate schemes can also be devised for this purpose, but this particular method requires only additional ADCs (and some penalty in data transfer rates). Note that for two detector modules in time coincidence, each with two phoswich scintillators, three unique hit combinations can occur: both hits in BGO, both in LSO or one in LSO and one in BGO.

Data Acquisition

Each PSPMT has nine outputs, eight position signals (4X, 4Y) and one dynode signal, If all of these signals are acquired from every PSPMT, then provision must be made to acquire 128 position signals and 16 dynode signals, 144 in total. There are a great variety of ways in which the number of data and digitization channels can be reduced. First, coincidence events will identify only a pair of detector modules, a total of 18 signals (16 position, 2 dynode). If it is also necessary to acquire a second dynode signal for a second integration window for each module, a total of 20 signals is needed per coincidence event. Acquisition of data in this way is the most general and nothing is discarded.

Virtually any algorithm can be applied retrospectively to these data if acquired in LIST mode. If this readout mode is "sparse" (only non-zero events are read out), an event consists of 20 signals x 2 bytes per signal = 40 bytes/event. Many schemes can be implemented to reduce both the signal number and the number of signals that ultimately must be digitized, but at some loss in generality. We shall assume that the 40 bytes/event, LIST mode method just described is employed, at least initially. It should be noted that this (large) event size reduces the maximum acquisition rate substantially so that alternative methods of signal reduction and digitization should not be ruled out.

Alternative hardware-based methods can also be used, potentially, to reduce the number of signals that need

to be processed. For example, the sixteen tubes can be arranged in banks of four tubes each. All tubes in a bank then have their first anode wires connected together, all second anode wires connected together, up to all eight anode wires connected together in this same manner. The total number of wires emanating from a bank is, therefore, reduced from 8 x 4 = 32, to 8, a four-fold reduction. In order to identify which pair of tubes in two different banks has registered a coincidence event, the last dynode signal from each tube is fed separately to a coincidence logic module that effectively encodes the detector pair. In this scheme, 16 coincidence channels are needed and 4 x 8 =32 signal channels from the 4 banks, a total of 48 channels. Without this scheme, the total is 144, as noted above. It should be noted, however, that by connecting corresponding anode wires together positioning accuracy may degrade. It remains to be determined experimentally whether this scheme is viable.

Other hardware methods exist that reduce the number of signals still further. Resistive division of the anode wire signals for each tube, example, a standard method is easily implemented and will immediately reduce the signal number by a factor of 2, from 8 to 4 per tube.

Conclusion

The invention has now been described with reference to the preferred embodiments. Alternatives and substitutions will now be apparent to persons of skill in the art.

In particular, although a circular ring is described, square, rectangular, or other support structures can be utilized to support the detectors. Additionally, the scintillator crystals may have shapes such as circular cylinders or other elongated shapes having a long axis parallel to the ring axis. Further, phoswiches having more than two crystals or having a single crystal with different scintillation signatures along the crystal axis may also be utilized.

Accordingly, it is not intended to limit the invention except as provided by the appended claims.

WHAT IS CLAIMED IS:

1. A positron emission tomography scanner comprising:

a ring positioned about a ring-axis and oriented perpendicularly to the ring axis; and

a first detector including a detector array of cylindrical scintillation elements having a base and a length, with array having substantially planar face formed of the bases of the cylindrical elements and with the lengths oriented perpendicularly to the detector face with the detector oriented so that the lengths of the cylindrical scintillation elements are oriented perpendicularly to the ring-axis and the detector is facing sideways.

2. The scanner of claim 1 wherein:

said ring has front and back sides;

and further comprising:

a second detector;

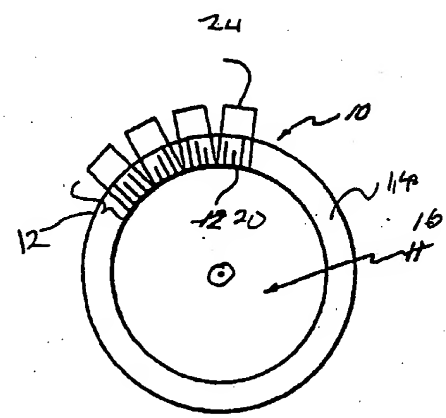
wherein said first and second detectors further comprises a photomultiplier tube (PMT) having said detector array attached to a face thereof; and

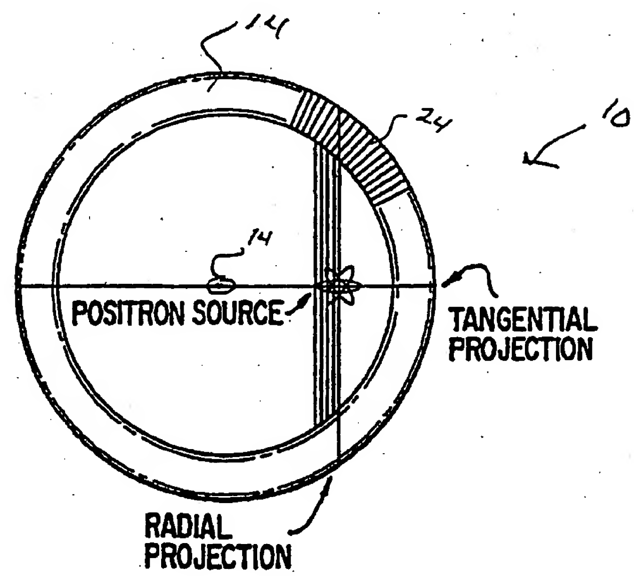
wherein said first detector is attached to said ring so that its PMT projects from the back side of said ring and said second detector is attached to said ring so that its PMT projects from the front side of the ring so that both detectors are facing sidewise and the detector arrays can be adjacently positions because the PMTs are on opposite sides of the array.

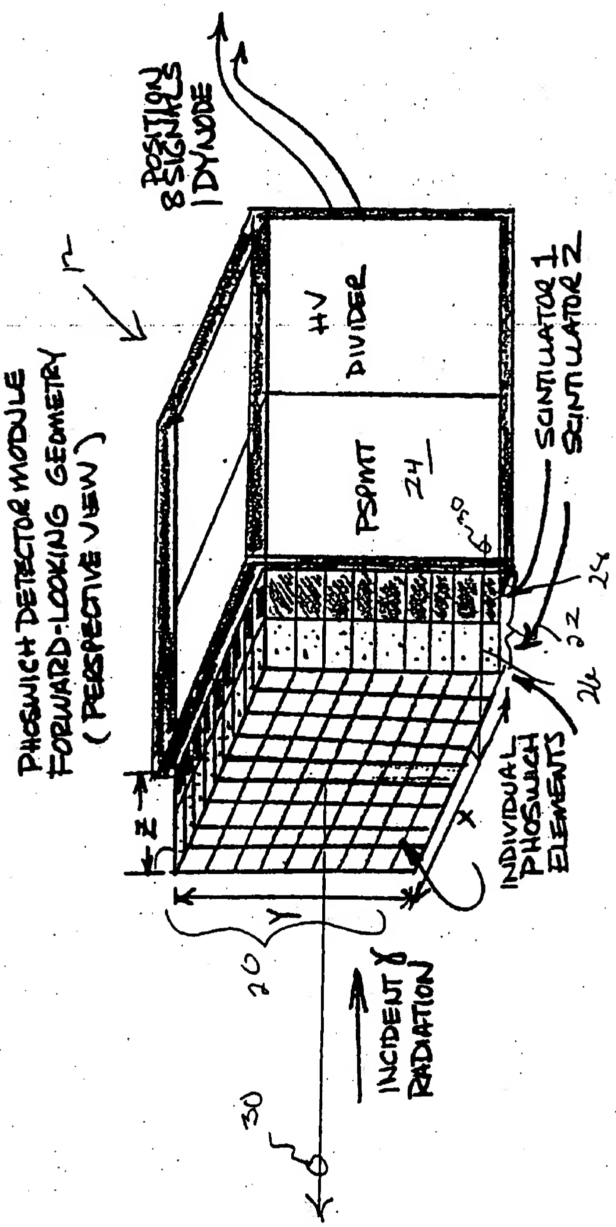
3. The scanner of claim 1 wherein:

each scintillation element is phoswich partitioned lengthwise into at least two regions having different scintillation signatures so that region in which scintillates in response to a gamma ray can be identified.

4. The scanner of claim 2 wherein said ring is circular.


24
10
14a
16
12
12 20
11


14
24
10
14
POSITRON SOURCE
TANGENTIAL
PROJECTION
RADIAL
PROJECTION



PSPMT : POSITION SENSITIVE PHOTOMULTIPLIER TUBE
HV: HIGH VOLTAGE

FIGURE 2

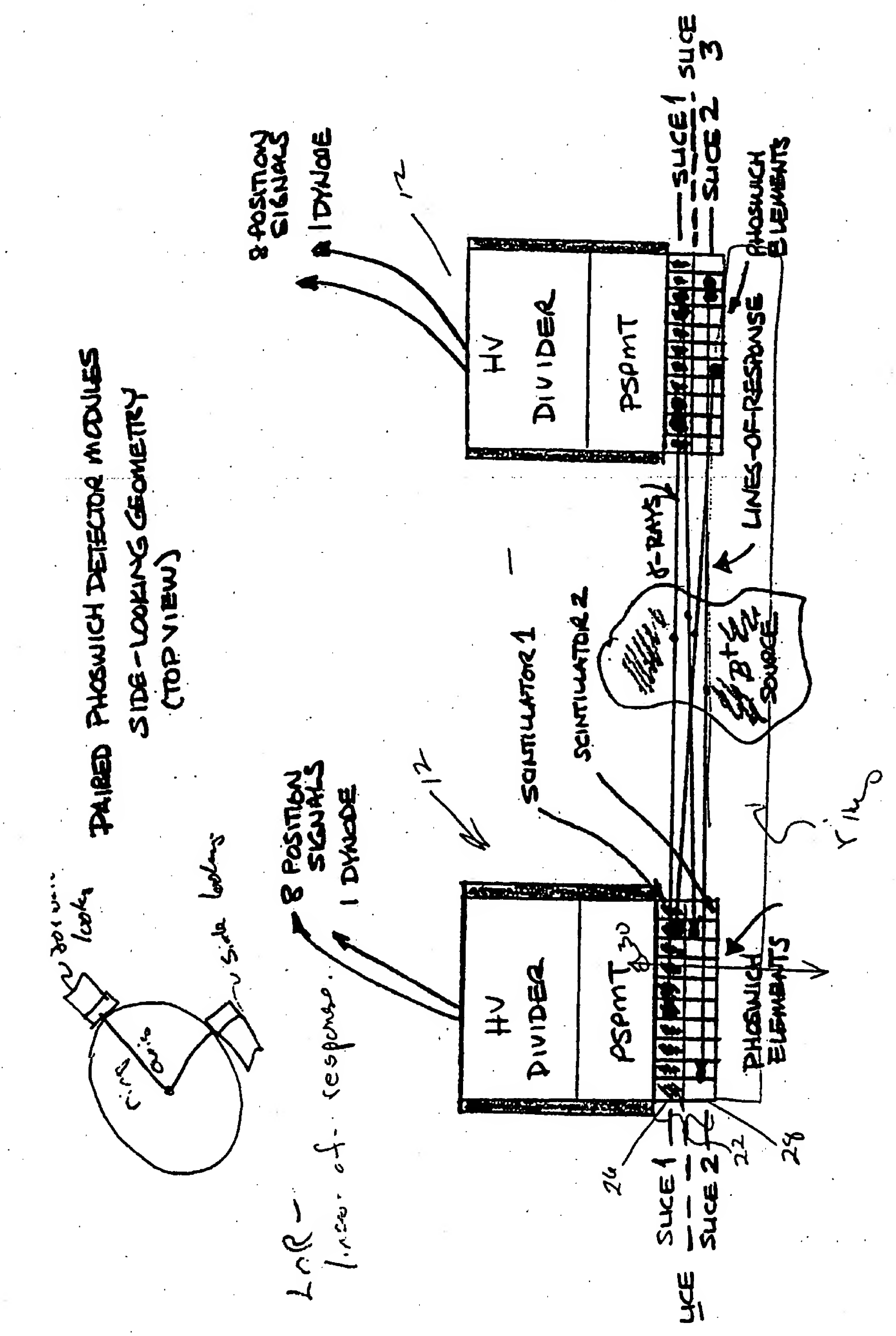

PAIRED PHOSWICH DETECTOR MODULES
SIDE-LOOKING GEOMETRY
(TOP VIEW)
8 POSITION SIGNALS
1 DYNODE
HV DIVIDER
PSPMT
30
12
SCINTILLATOR 1
SCINTILLATOR 2
γ-RAYS
LINES-OF-RESPONSE
β+ SOURCE
PHOSWICH ELEMENTS
SLICE 1
SLICE 2
SLICE 3
22
24
26
LoR —
lines of response
side looking

FIGURE 4

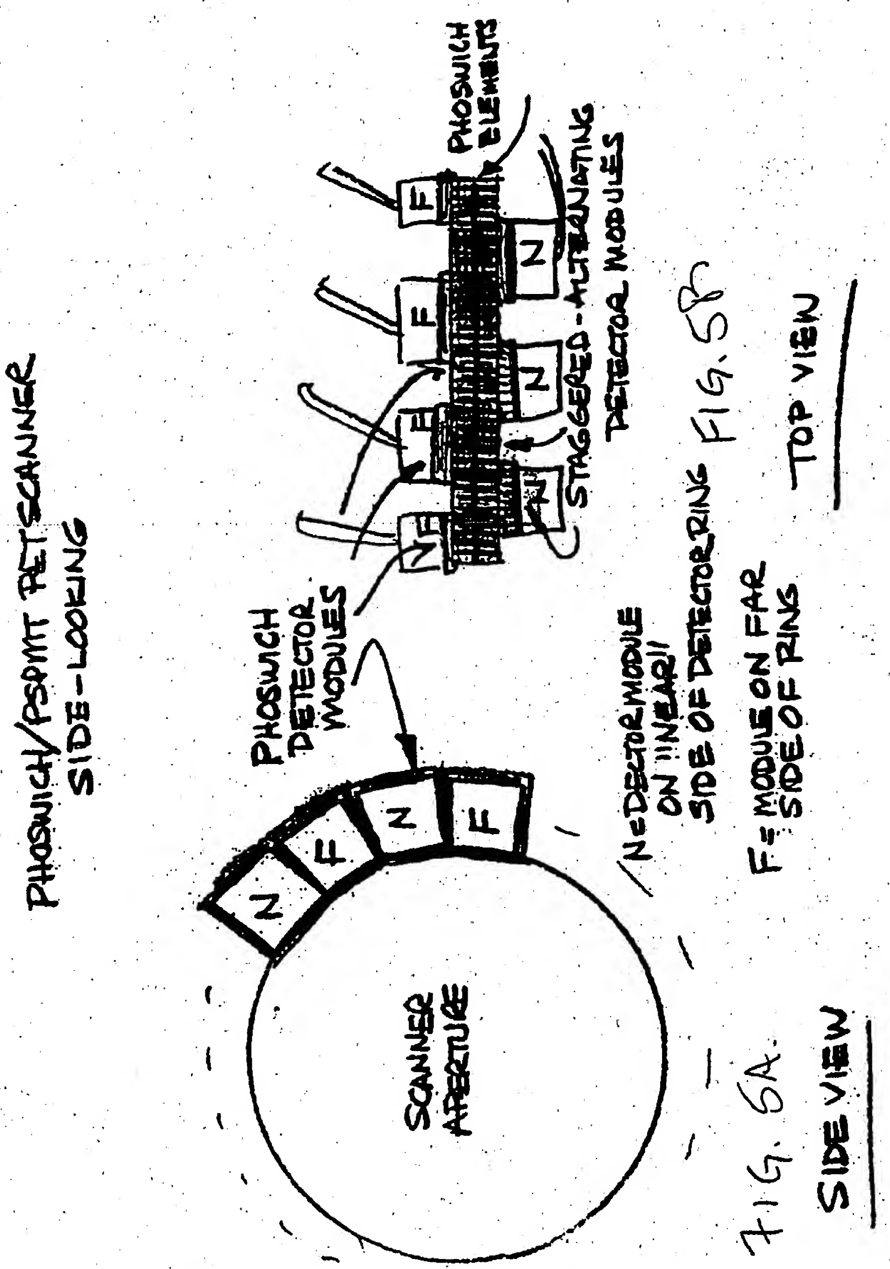

PHOSWICH/PSPMT PET SCANNER
SIDE-LOOKING
SCANNER APERTURE
N
F
N
F
PHOSWICH DETECTOR MODULES
N=DETECTOR MODULE ON "NEAR" SIDE OF DETECTOR RING
F= MODULE ON FAR SIDE OF RING
SIDE VIEW
PHOSWICH ELEMENTS
STAGGERED - ALTERNATING DETECTOR MODULES
TOP VIEW

FIG. 5A

FIG. 5B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/22875

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01T1/29

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	EP 0 219 648 A (CLAYTON FOUND RES) 29 April 1987 see abstract see column 4, line 45 - line 5; figures 1-3	1,3 2
X A	GB 2 198 620 A (HAMAMATSU PHOTONICS KK;RESEARCH DEV CORP) 15 June 1988 see page 9, line 12 - line 15; figure 4	1 2
A	GB 1 603 272 A (PHILIPS NV) 25 November 1981 see page 2, line 12 - line 42; figure 1	2

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 March 1999	08/03/1999

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 98/22875

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